Co-Processed Ceramic Insulation
for High Field Accelerator Magnets

VLHC Magnet Technologies Working Group
Workshop II: Magnets for a Very Large Hadron Collider

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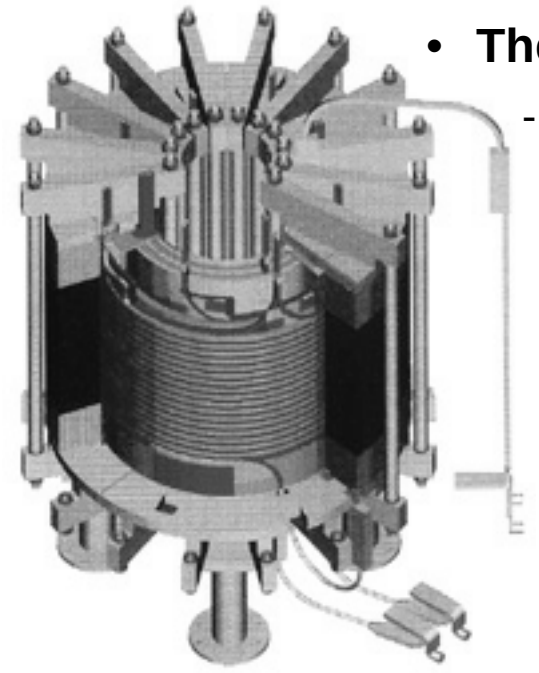
Material Solutions...

Insulation • Adhesives • Coatings • Composites

World's Largest Magnet



- **The ITER Central Solenoid (CS) Model Coil**
  - **Successfully tested recently in Japan**
    - **One of the world's largest superconducting magnets**
    - **Coil ramped to 13T; no training or quench was observed**
    - **CTD-112P pre-preg epoxy is the primary insulation!**

- **CTD developed radiation resistant glass/epoxy insulation for use in ITER superconducting magnets.**
  - **Met ITER property requirements after exposure to >10^9 Rads**
  - **CTD developed insulation application processes and provided extensive engineering and material testing support**

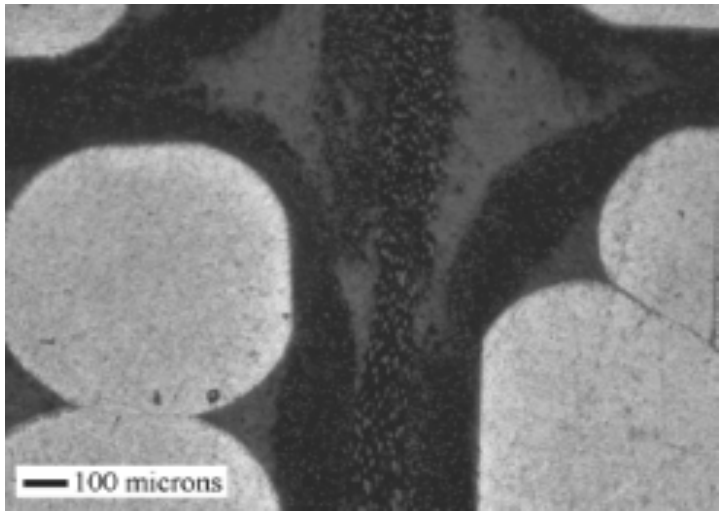
Co-Processed Ceramic Insulation for VLHC Magnets

- Review of Magnet Insulation Needs
- Introduction to Wrappable Ceramic Insulation
- Thermal Expansion
  - Wrappable Ceramic Insulation vs. Glass Epoxy Insulation
  - Comparison of Conductor / Insulation Stacks
- Approach to lowering the cost of the Wrappable Inorganic Insulation
  - New matrix materials
  - New reinforcement materials
  - New application techniques
    - Pre-preg tape
    - Vacuum Pressure Impregnation (VPI)
- Impact of Wrappable Ceramic Insulation on overall magnet costs

Goals for New Insulation

Magnet Goals

- Improve magnet performance
- Reduce magnet costs
- Improve reliability/reduce risk
- New insulation application processes
  - Greater latitude for the coil designer



Insulation Parameters

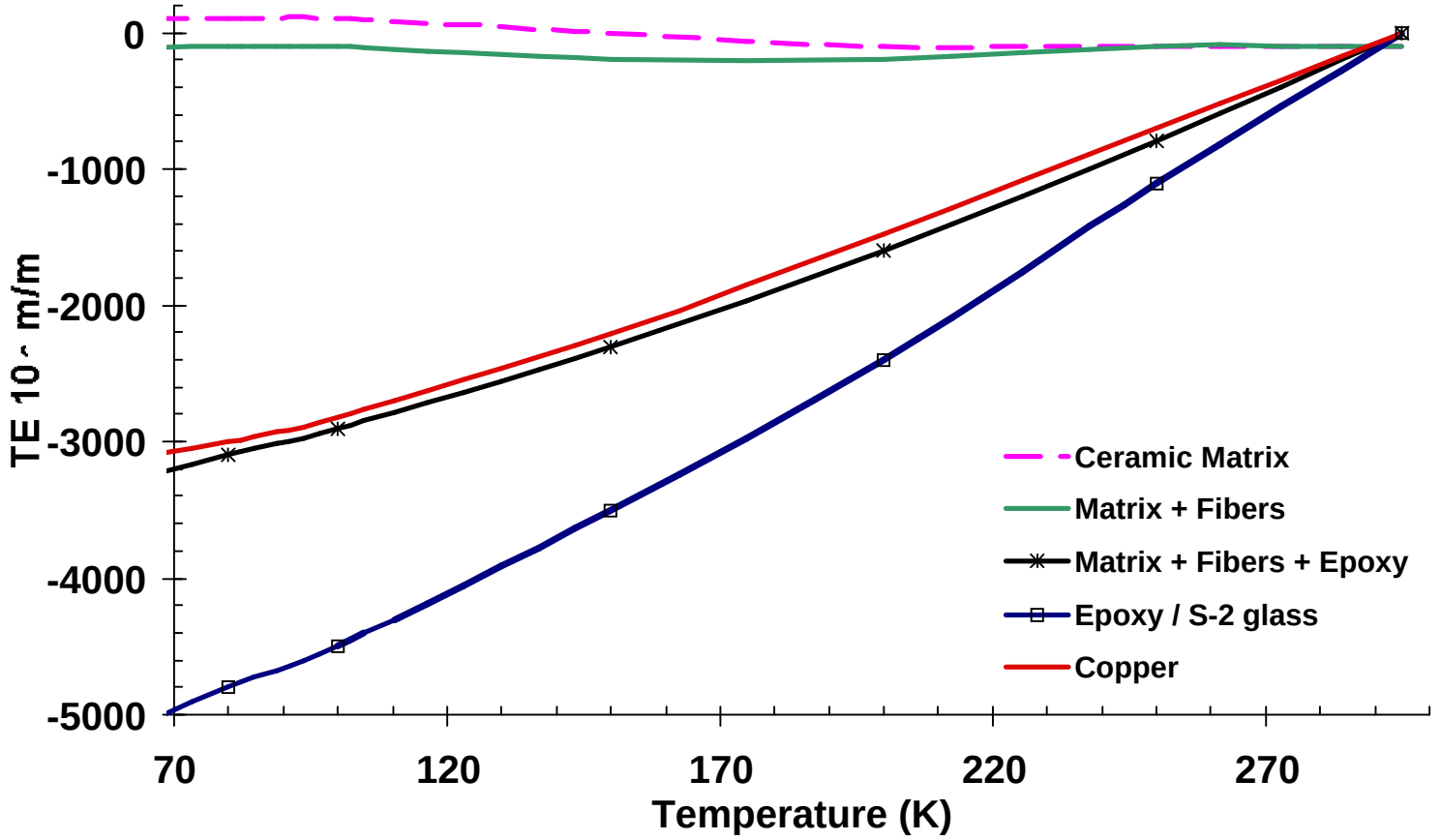
- Mechanical Properties
  - Improve toughness, modulus, strength
- Increase Electrical Properties
  - Increase dielectric strengths
  - Enable close packing
- Thermal Properties
  - Match thermal contraction
  - Increase thermal conductivity
- Radiation
  - Reduce organic content
- Chemical Compatibility
  - Address poisoning issues in A15 and HTS
- Wind and react
  - Co-react insulation with superconductor
  - Reduce manufacturing time/cost

What is Wrappable Ceramic Insulation

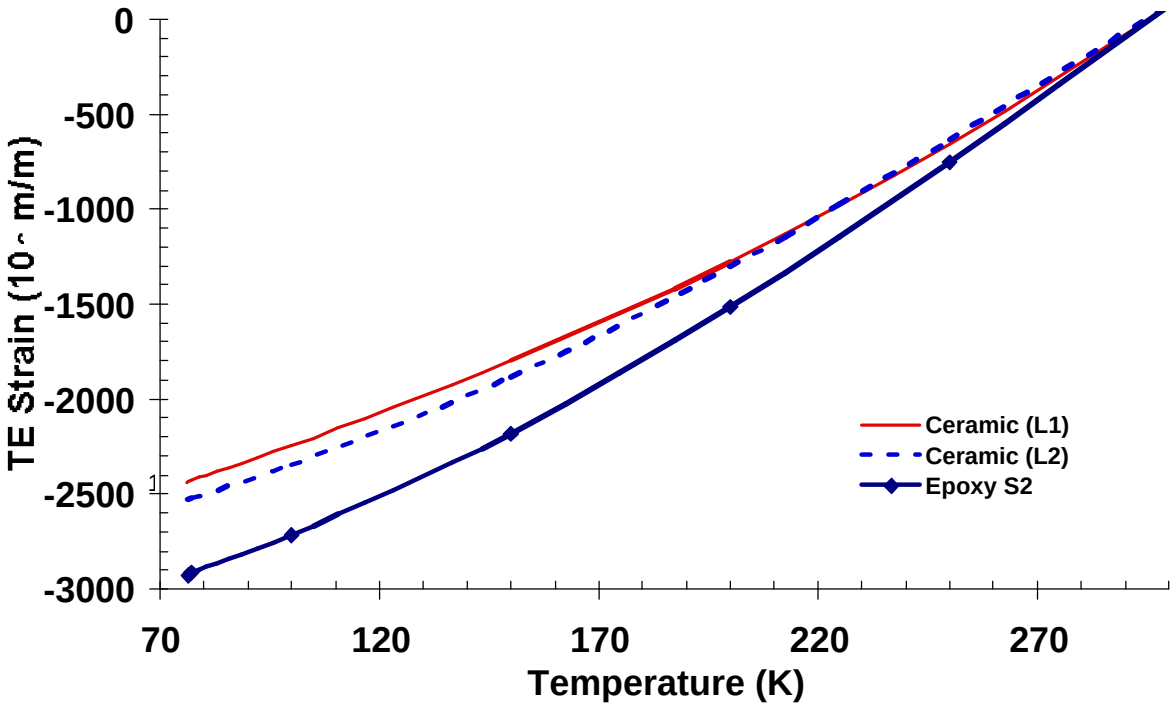
- Electrical insulation with properties similar to or better than epoxy insulation while using conventional processing methods
  - Enhanced radiation resistance
  - Up to 2x modulus performance
- Apply insulation BEFORE heat treatment
  - Ceramic fibers and inorganic binder applied prior to heat treatment
  - Epoxy impregnation performed after heat treatment
- Process using SAME equipment as epoxy insulation and under the SAME superconductor heat treatment conditions
- Coil can be handled as a monolith
  - After initial cure of inorganic binder
  - During and after heat treatment
  - No special tooling required

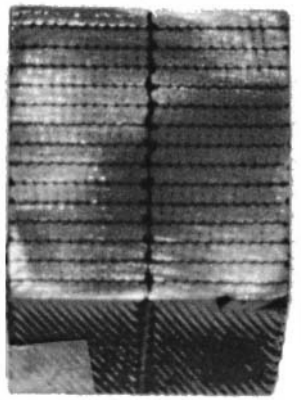
Thermal Expansion Characterization

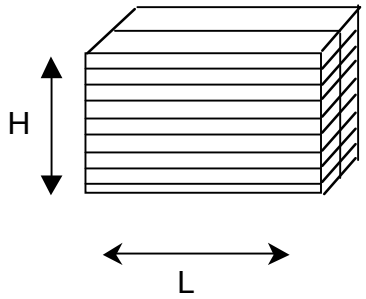
- **Comparison of conductor and ceramic insulation thermal expansion**



Thermal Expansion of Composite Stacks



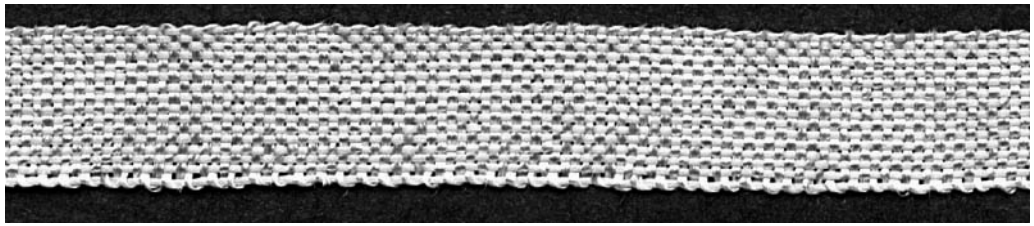




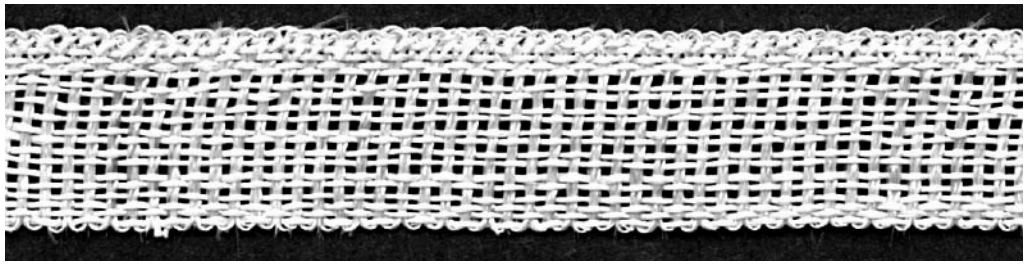
Insulation Cost Reduction Efforts

- **Identified alternative matrix formulations with lower costs**
  - **Need to evaluate matrix performance**
  - **New matrices designed for pre-preg and VPI**
  - **Will investigate all inorganic systems**
- **Ceramic fiber reinforcement**

Ceramic fabric tape, CTD CF100; 12.5 mm wide x 0.125 mm thick

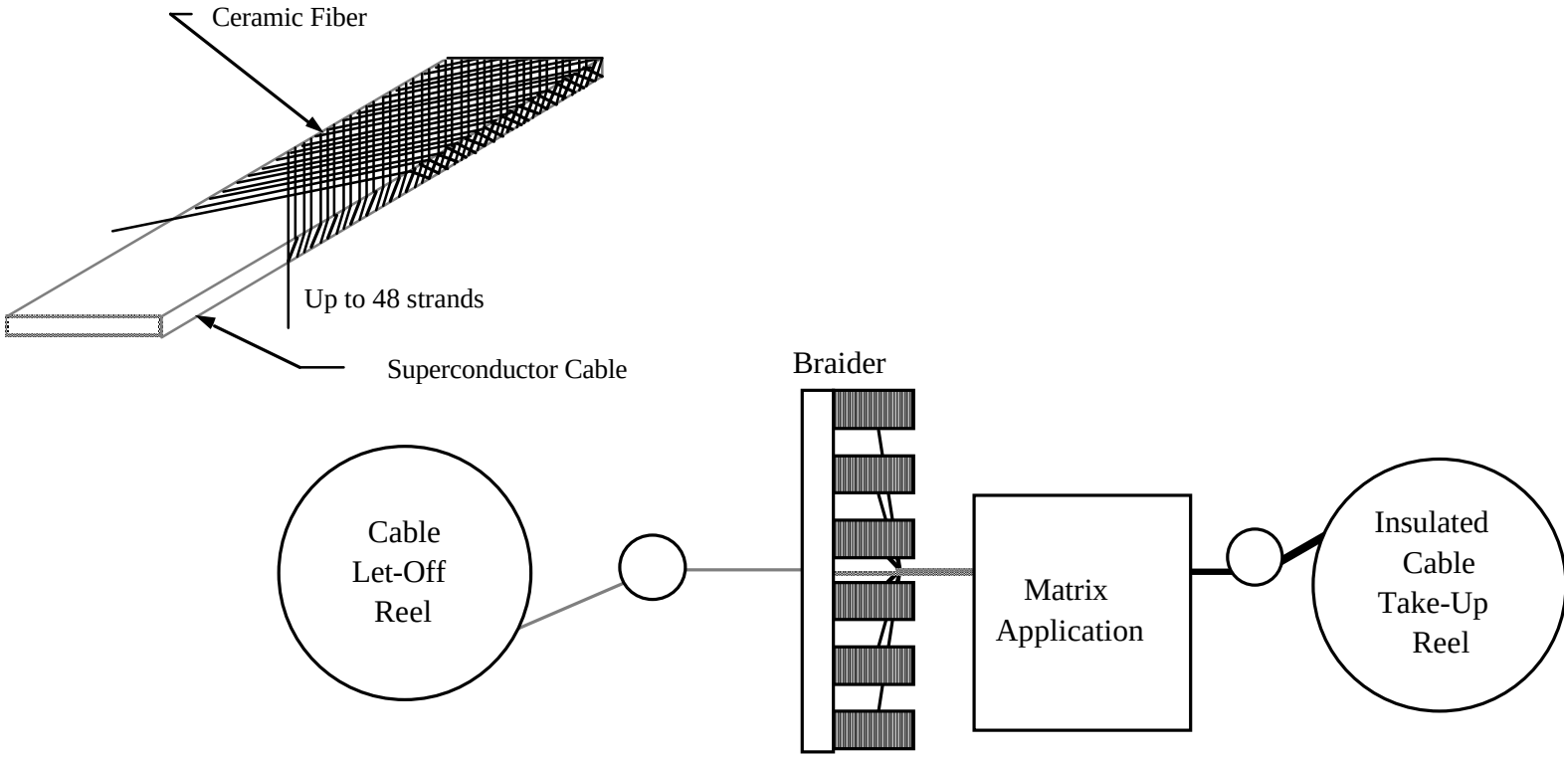


Lower cost alternative for custom woven ceramic tape



Insulation Cost Reduction Efforts

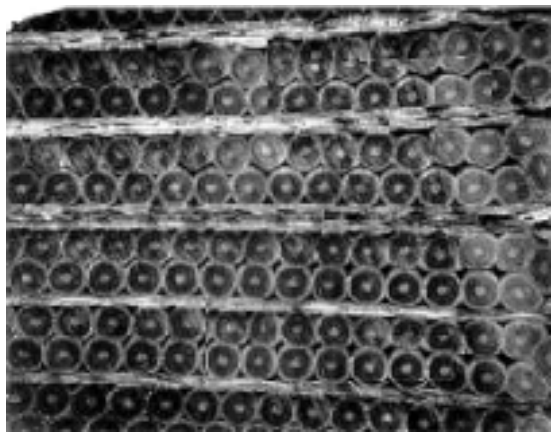
- **Lower cost alternatives for ceramic reinforcement**
  - **Insitu braiding of ceramic fibers onto superconducting cable**



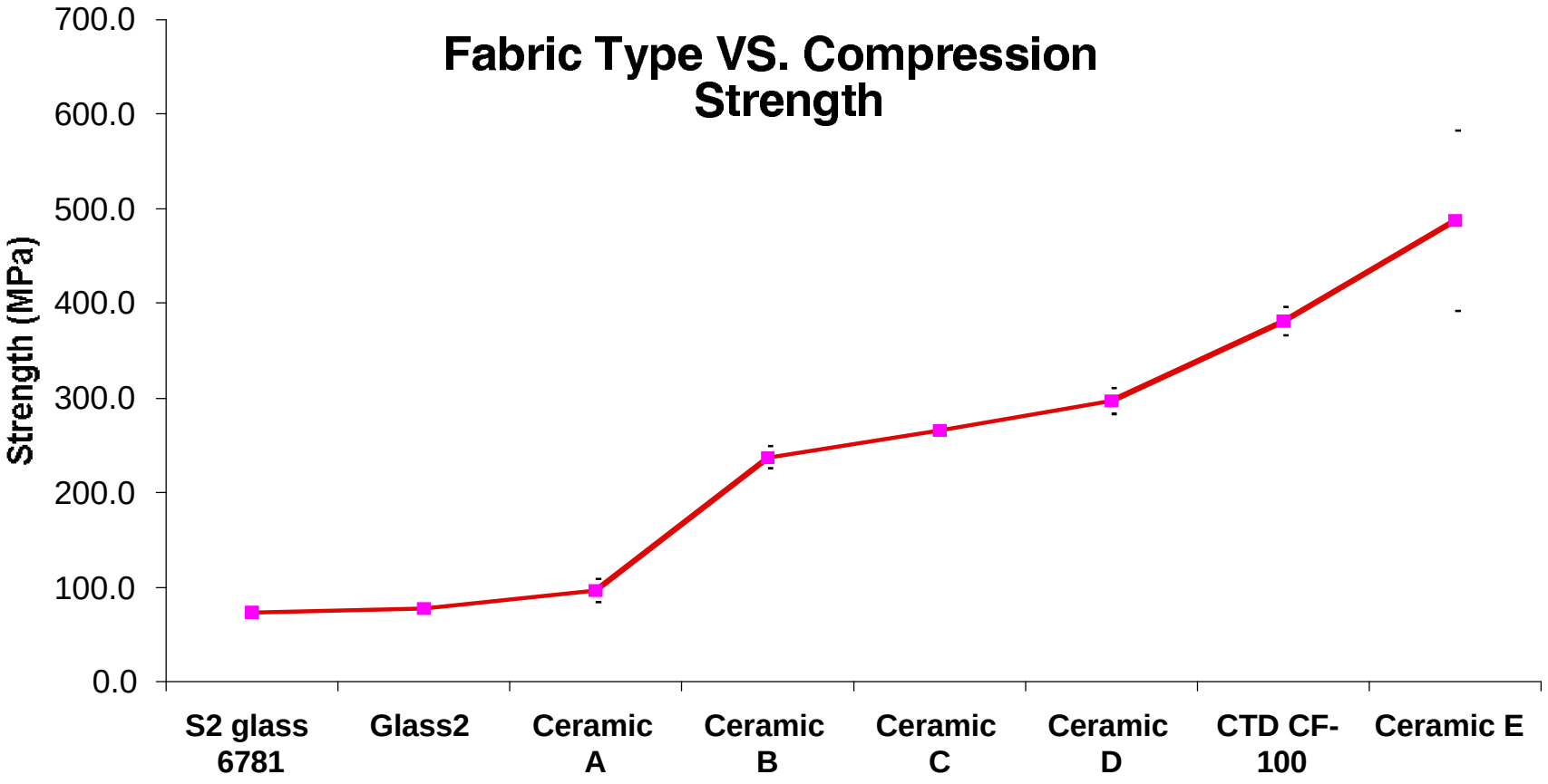
Insulation Cost Reduction Efforts

- **Fiber heat treatment options**
  - **Ceramic fabric is heat treated to achieve best laminate properties**
  - **What is the impact of the heat treatment on stack performance?**

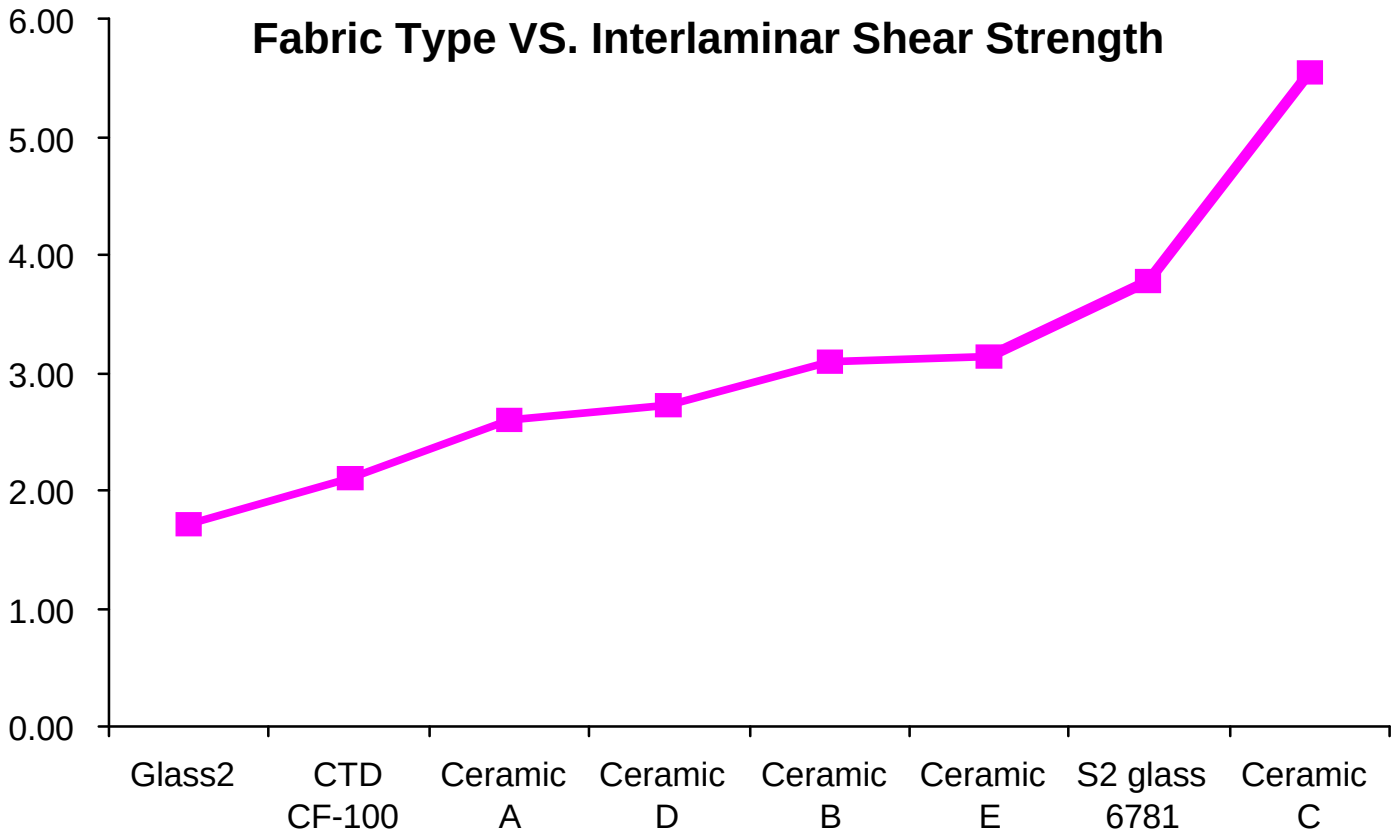
- **Alternative ceramic fibers, fabrics, and papers**
  - **Identify and evaluate commercially available new or alternative reinforcements**
  - **Will consider modification to commercial products to meet magnet insulation needs**



Glass Fiber Reinforcement



Glass Fiber Reinforcement



Impact of Wrappable Inorganic Insulation on Overall Magnet Costs

- **Feedback from magnet researchers**
  - **Big change in how magnets perform**
  - **Better mechanical and radiation performance**
  - **Simplified, lower cost, lower risk coil fabrication**
- **Inorganic binder enables:**
  - **Use of existing tooling used with NbTi coils**
  - **Coil behaves as a monolith**
    - **Before, during, and after heat treatment**
- **Interest in quantifying savings**
  - **Reduced manufacturing costs**
  - **Improved performance**
  - **Reduced scrap rate**